ROBotic Open-architecture Technology for Cognition, Understanding and Behavior

Project no. 004370

RobotCub

Development of a cognitive humanoid cub

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

RC_IST_100_D_000_08_HEAD DESIGN

Design and Development of a Robot Head

Internal Report

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Responsible Person: José Santos-Victor, Instituto Superior Técnico (IST).
Authors: Ricardo Beira, Manuel Lopes, Miguel Praça, Alexandre Bernardino and José Santos-Victor, Instituto Superior Técnico (IST)

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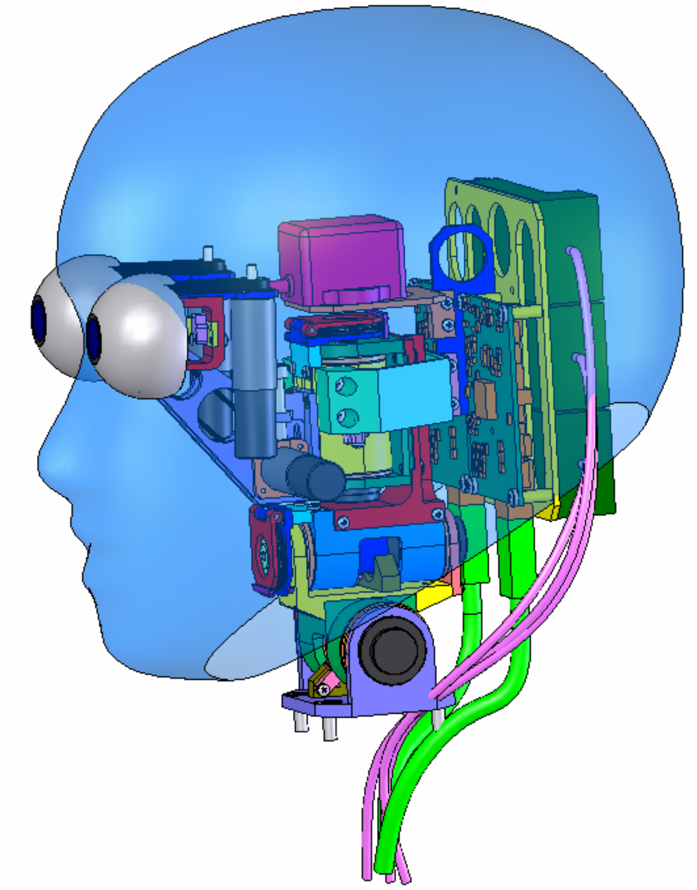

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1 Mechanism Specifications

This section explains how we get the anthropomorphic data and specifications for the iCUB robot head. Overall, the iCUB dimensions are those of a two-year-old human child, so that iCUB can perform tasks similar to those performed by human children.

1.1 Dimensions

The dimensions of the head/neck of the robot, as well as the positions and size of its facial features, have realistic anthropomorphic values shown in Figure 1.

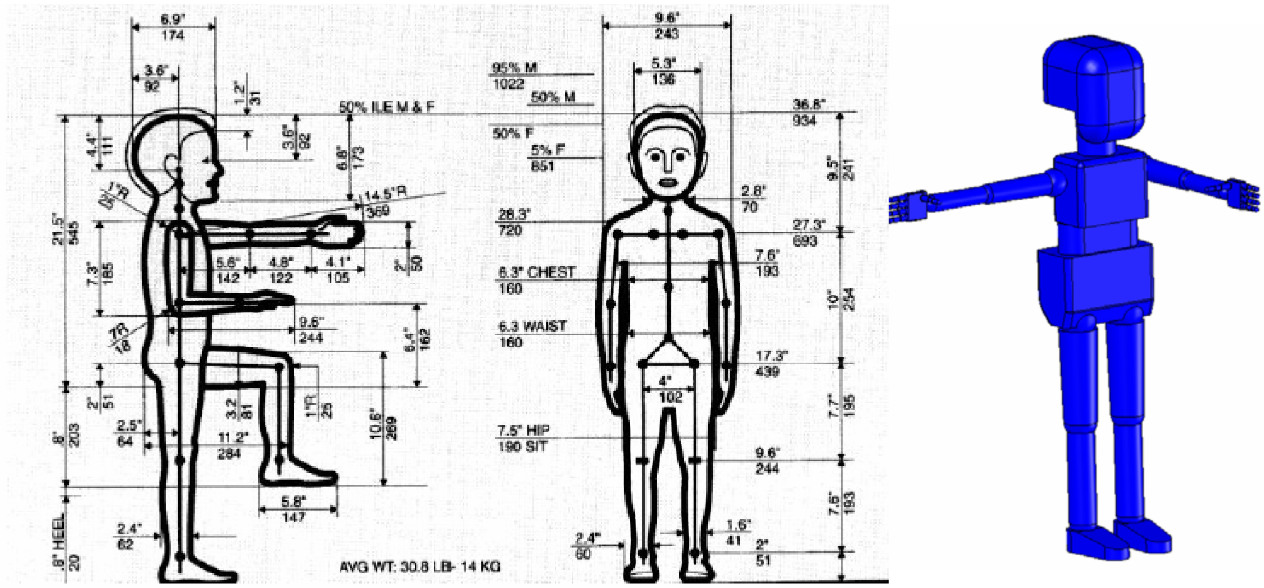


Figure 1 - Left: Approximate size targeted for the Robot-cub. Right: CAD Model, with the desired dimensions [Telerobot].

1.2 Head Degrees of Freedom

In order to guarantee a good representation of the human movements, the iCUB head contains a total of 6 DOFs: neck pan, tilt and swing and eye pan (independent) and tilt (common) as shown in Figure 2.

Facial expressions are not included yet. It would be interesting if the robot could use a minimal set of facial expressions (implying the smallest possible number of motors or moving parts) to convey information about its emotional status.

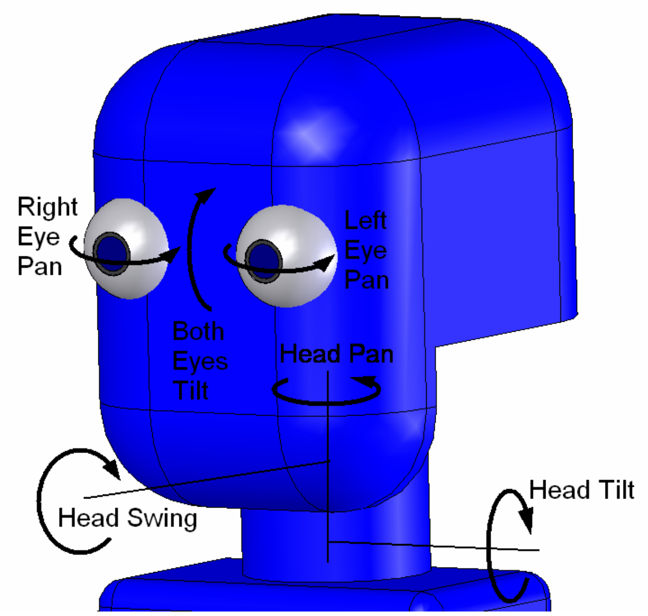


Figure 2 - Illustration of the Head degrees of freedom. There is a total of six degrees of freedom, three for the neck and three for the eye system (facial expressions are not included)

1.3 Range of Movements

The definition of the iCUB head range of movement was taken from biomechanical data [2] and it is summarized in Figure 3.

Joint		Range [º]
Eyes	pan	-45 to +45
	tilt	-40 to +40
Neck	pan	-55 to +55
	tilt	-50 to +40
	swing	-40 to +40

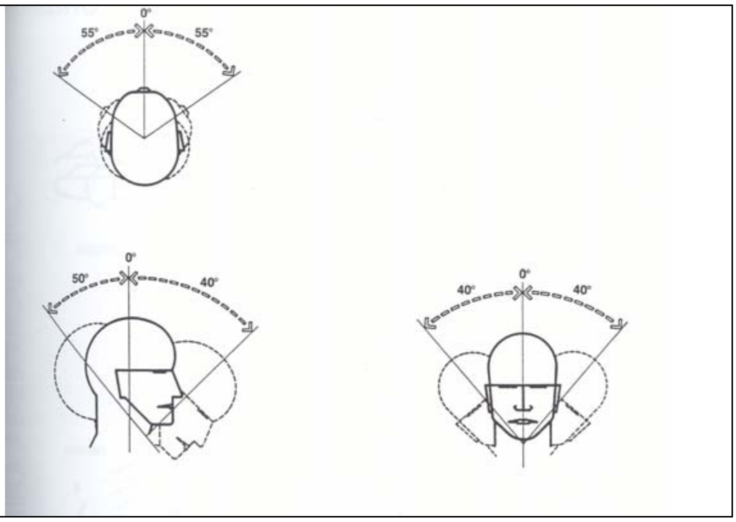


Figure 3 - Motion Range of Each Joint and Realistic Human Movements [2]

1.4 Velocities/ Accelerations

Human eye movements are classified into smooth pursuit, saccadic, and involuntary movements. The saccadic eye movement and smooth pursuit movement occur when the eyes pursue an object.

The speed of the smooth pursuit eye movement is relatively low (up to ~30º/s). Saccadic eye movement is a high speed jumping movement, with a maximum speed in the range of a few hundreds degrees per second. The saccadic eye movement occurs when the eye ball movement can not pursue an object or when the human searches outside of the view. In order to achieve the human-like image processing, the iCUB head must move with comparable eye/head speeds.

In [3], we can find the eye/neck speed for human adults during saccadic movements with 2.5, 5, 10, 40, 60 degrees amplitude. The saccade speed increases with the motion amplitude.

Adult values Head Weight: 4-5-5Kg		Range [º]	Velocity [º/s]		Acceleration [º/s^2]	
			min	max	min	max
Eyes	pan	90	166	850	16000	82000
	tilt	80				
Neck	pan	110	23	352	330	3300
	tilt	90				
	swing/roll	80				
Neck/Eye (pan) ratio			14%	41%	2%	4%

Active Head Rotations and Eye-Head Coordination, Zangemeister and Stark
Saccades with amplitude of 2.5, 5, 10, 40, 60 degrees.

Table 1 - Anthropomorphic data, taken from the literature

From this table there are two observations relevant to the iCUB head design. First, we will use as specifications the smaller range of saccadic speeds since (i) these numbers are for adults and children must have significantly smaller speeds and (ii) small amplitude saccades are closer to smooth pursuit movements which are far more frequent during the robot's normal operation. Secondly, we will use the ratio between eye/neck velocity and acceleration as a design parameter. The neck speed is between 14 to 41% of eye speed and acceleration is between 2 and 4% smaller.

Using this information, and assuming that the eye movement will have a trapezoidal profile in position (as axes control boards usually specify), we can compute the necessary joint acceleration if we consider that the joint accelerates for a certain percentage of time (e.g 20%) before reaching maximum speed followed by an equal deceleration period (e.g. 20%). We then have:

Configuration Parameters

Neck/eye velocity ratio	50%	
Acceleration time	20%	of full excursion time. Same time used for decclerating.
{Swing, til}t / pan ratio	100%	in terms of velocity. Applied together with normalization by movement **range**
Eye pan max velocity	180,0	

		Range [º]	Vel Max [º/s]	Acceleration full range		
				ac.[º/s^2]	T [s]	mean vel
Eyes	pan	90	180,0	1440	0,625	144
	tilt	80	160,0	1280	0,625	128
Neck	pan	110	90,0	295	1,528	72
	tilt	90	73,6	241	1,528	59
	swing/roll	80	65,5	214	1,528	52

params
computed

Table 2 - Computed set of angular speed and acceleration for the various degrees of freedom of the Robot Cub Head.

2 Mechanical Design

The Mechanical Design involved in the iCUB head design could be basically divided in three major parts: Neck Mechanism, Eyes Mechanism and Cover.

During the design process we used these specifications and adopted the following criteria as desirable characteristics for the mechanism:

- DOFs., range of motion, joint speed and torque according to detailed specifications,
- Compactness and lightweight, to meet all the desired specifications (< 1.5 Kg),
- Modularity and simplicity of the structure to facilitate maintenance and assembly,
- Self-contained (except cables), to facilitate integration with the other parts of the robot
- Robustness, to resist the efforts suffered during its working period

2.1 Neck Mechanism

Up to now, we have proposed and developed a Serial and a Parallel neck mechanisms that have been prototyped and are subject of study. Additionally, we analyze a Cable Driven Mechanism (developed by Telerobot). The three designs are illustrated in Figure 4.

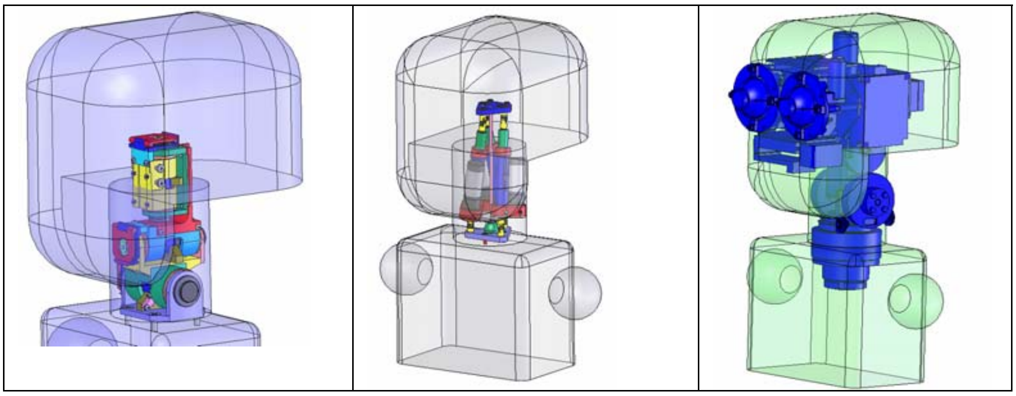


Figure 4 - Three Solutions for Neck Mechanism

2.1.1 Serial Mechanism

This solution consists of a serial manipulator, with three degrees of freedom, placed in a configuration that best represents the human movements. For driving this mechanism, DC micromotors (Faulhaber) with planetary gearheads have been used. An initial prototype was built and tested and demonstrated in a light tracking experiment.
It is also important to say that, in spite its simplicity, the mechanism is very robust, easy to control and has high performances, meeting all the desired specifications.
Each joint uses an overload clutch system (figure below) that increases the robustness of the mechanism, giving it the possibility to fall on the floor and suffer different kind of impacts and efforts during its interaction with the external world.

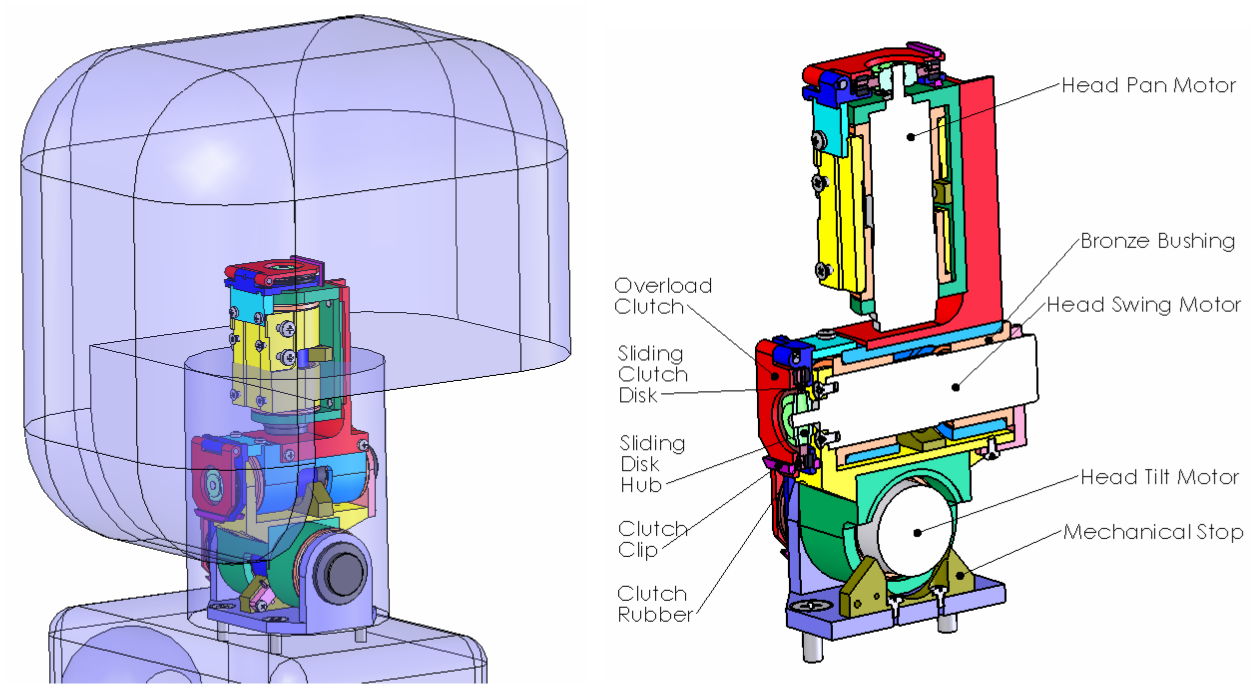
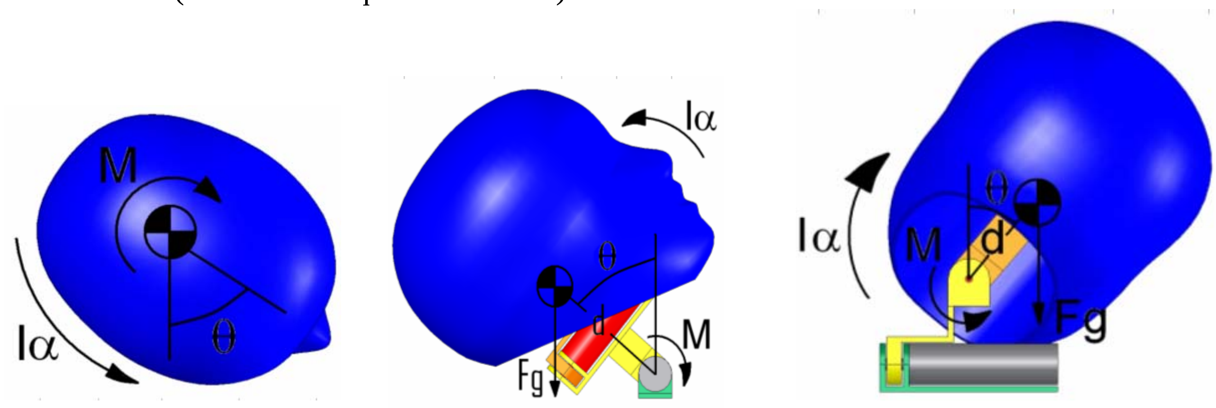


Figure 5 - CAD Model of Serial Mechanism

This calculation of the actuators design characteristics was based on the desired specifications and the Moments of Inertia, as well as the weight of the different components, given by the CAD software (Table 3 - Torque Calculation).



	d (m)	m (Kg)	Fg (N)	I (Kg.m^2)	θ (°)	Ang. Acceleration (°/s^2)	mNm
Neck pan	0,05	0,5	4,9	0,0013	90	294,5	251,68
tilt	0,075	0,7	6,86	0,011	90	241,0	560,77
swing/roll	0,065	0,57	5,586	0,0047	90	214,2	380,66

Table 3 - Torque Calculation

2.1.2 Parallel Mechanism

To be modular and self-contained, the head structure must support a large number of mechanical and electrical components. On the other hand, high torque motors are required to drive the cameras in velocities similar to saccades. So, to satisfy both (conflicting) requirements, one interesting solution for the robot neck structure is based upon a parallel mechanism. Parallel mechanisms have remarkable characteristics such as high precision and high load capacity, high rigidity. Also, since all motors are fixed on the base, the inertia of the moving part is relatively small.

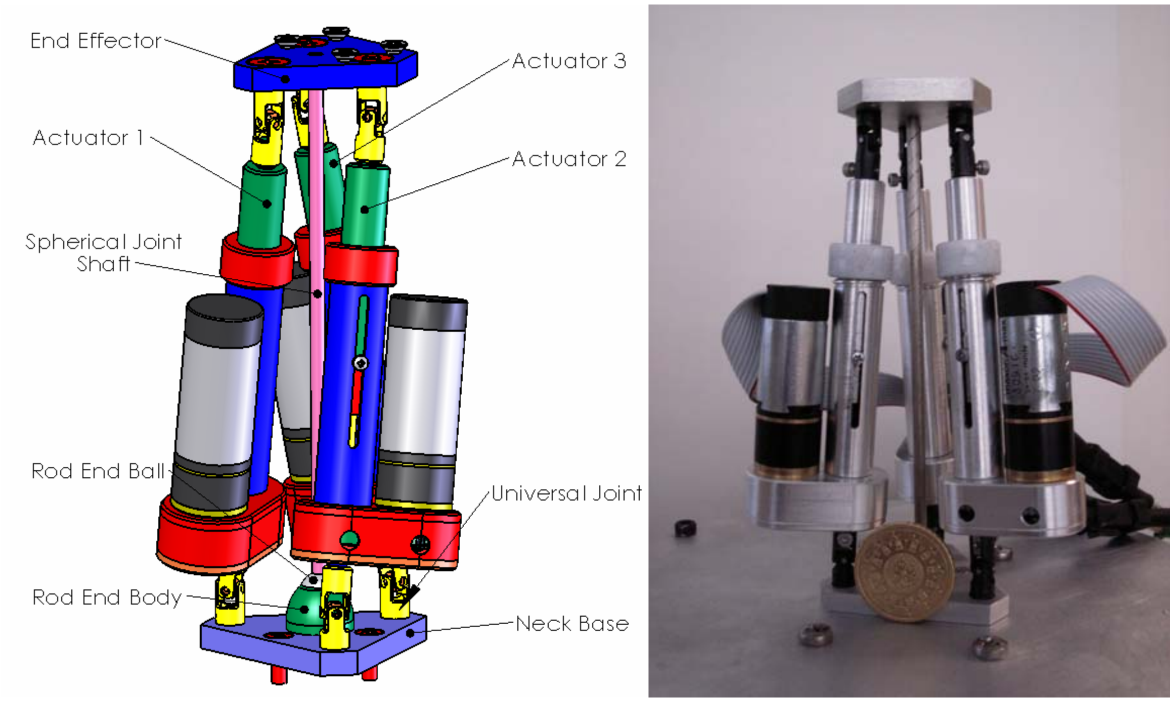
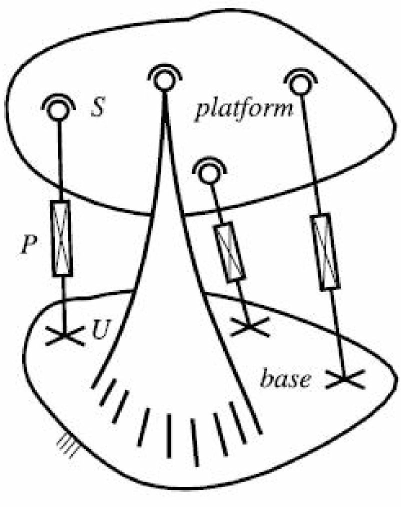


Figure 6 - CAD Model of the Parallel Neck and prototype.

The mechanism is moved by three Linear Ball Screw Actuators (Figure 7). Comparing with other solutions, this type of actuators shows a good compromise between size, controllability and load capacity. The mechanical structure of these components is illustrated in Figure 7.



In this architecture, the platform and the base are joined by a passive spherical pair. The platform orientation is controlled by three legs of type UPS (U, P and S stand for universal joint, prismatic pair and spherical pair, respectively), the prismatic pair being the actuated joint. This parallel wrist has the advantage of being a three dof mechanism (spherical motion) and has the drawback of having reduced workspace because of the passive spherical pair [5].

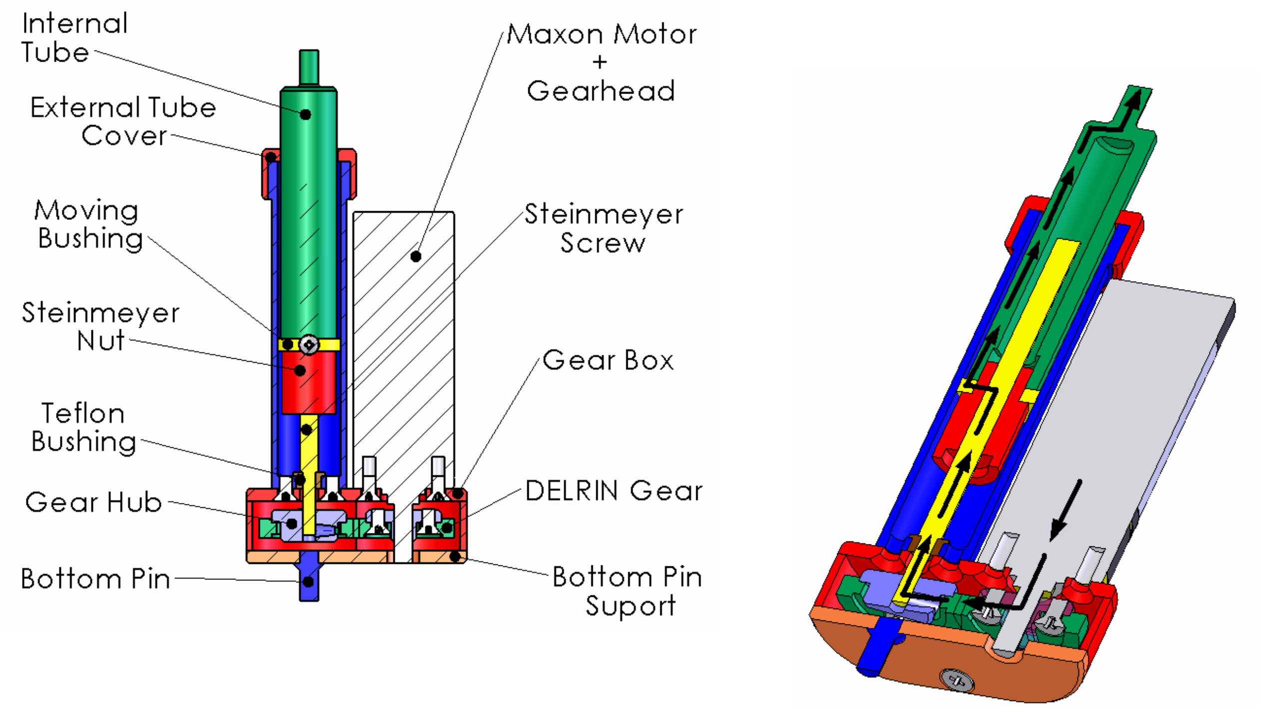


Figure 7 - Ball Screw Linear actuator

The three actuators were designed and the inverse kinematics computed with Matlab. The dynamic analysis (to assess the required torques) was done with CosmosMotion having the Dimensional, Kinematical and Dynamic Specifications as inputs. As a result of this analysis, we obtained the values of actuator stroke, maximum velocity and load capacity.

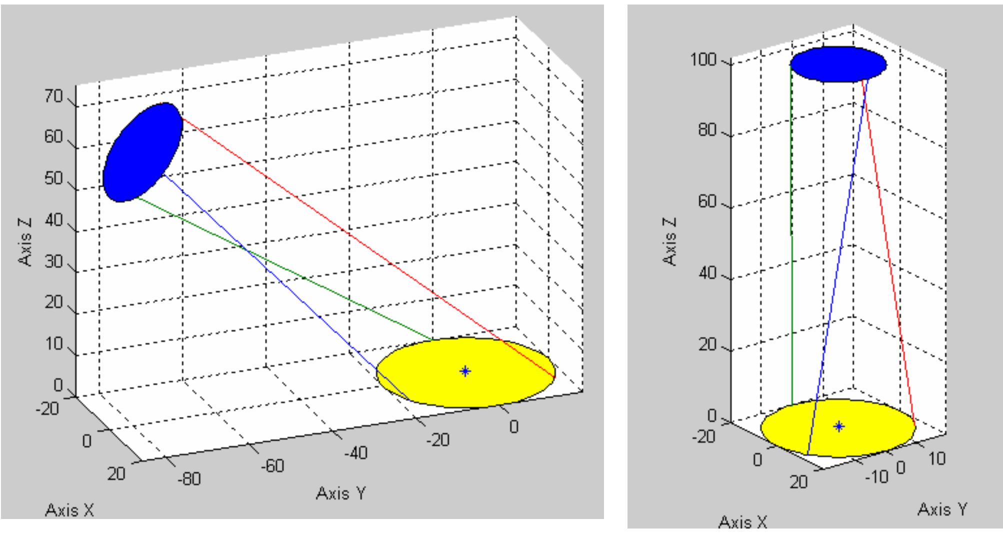
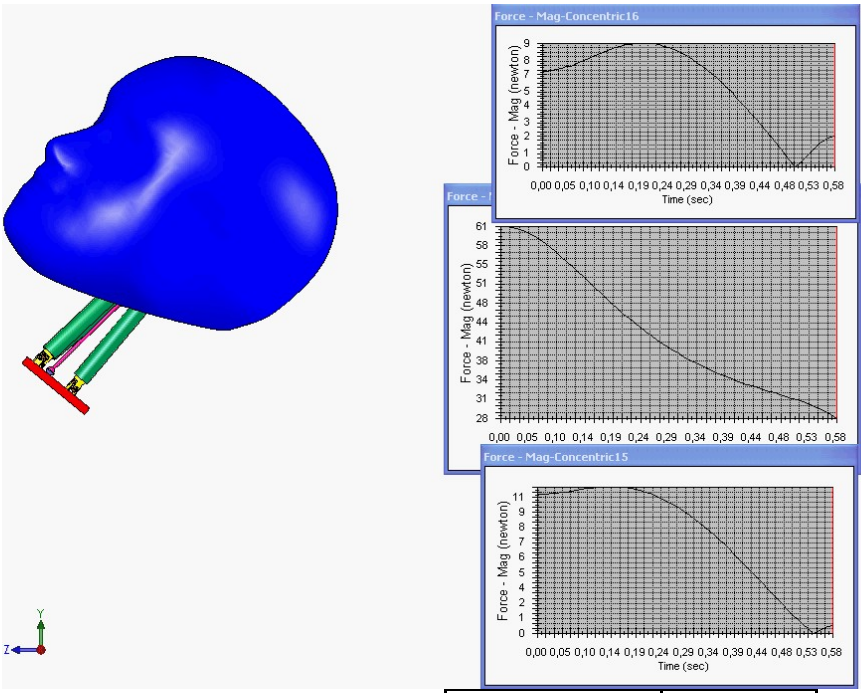


Figure 8 - Inverse Kinematics Simulation



Characteristics	Output
Stroke	30mm
Max. Velocity	30mm/s
Load Capacity	62 N

Figure 9 - Dynamic Simulation Linear and Ball Screw Actuator's Characteristics

2.1.3 Cable Driven Mechanism

The neck version proposed by TeleRobot is based on a cable based transmission. A cable driven transmission consists of a pulley, a smaller diameter pinion and a cable that wraps around both the pulley and the pinion.
The principle is the same as in gear transmissions, except that force is transmitted by tension in the cables and not by contact between gear teeth. Speed reduction, similar to gear transmissions, is proportional to the ratio of pulley and pinion diameters.

In spite the fact that there is not a lot of detail (e.g. specifications on speed, acceleration, weight, etc) the following observations can be made regarding this Cable Driven Mechanism:

Positive aspects

- unlike belt drive, the cables are terminated at each end and torque is transmitted to the pinion by several turns of cable to prevent slippage
- cables do not experience wear or friction like gearboxes and therefore do not require lubrication
- Ensure a good transportation of the electrical wires (cabling)

Negative aspects

- Does not seem sufficiently compact (it is larger than the desired neck diameter and the motors may use substantial space of the robot upper torso). Details not available.
- Complexity of the mechanism. Doesn't seem easy to assemble or assist.

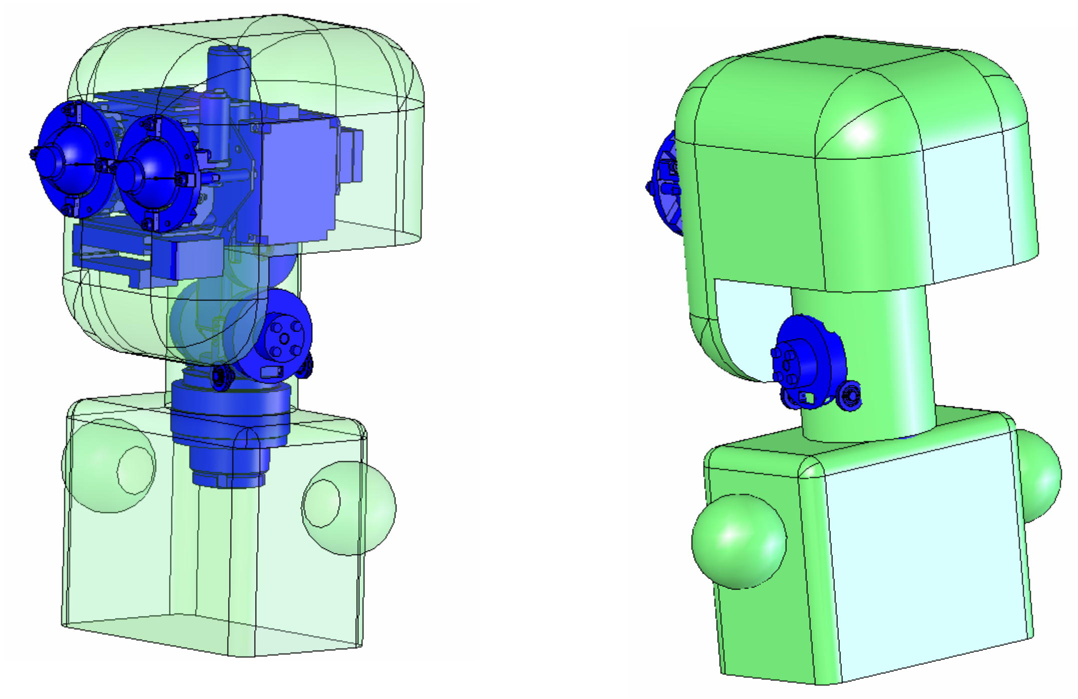


Figure 10 - CAD Model of the Cable Driven Mechanism

2.2 Eyes Mechanism

The eyes mechanism has a total of three degrees of freedom.
Both eyes can pan (independently) and tilt (simultaneously). The pan movement is driven by a belt system, with the motor behind the eye ball. The eyes (common) tilt movement is actuated by a belt system placed in the middle of the two eyes. Each belt system has a tension adjustment.

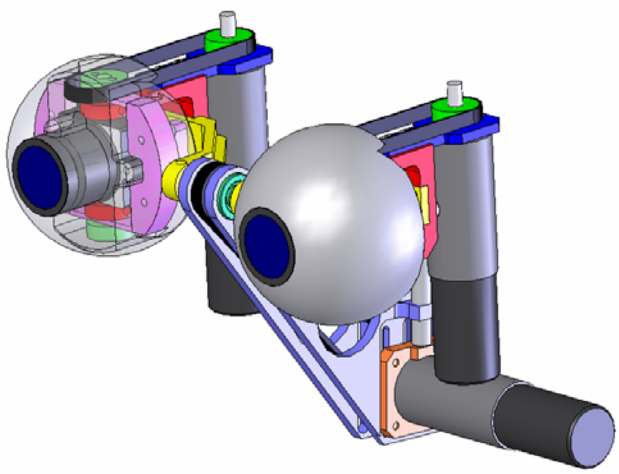
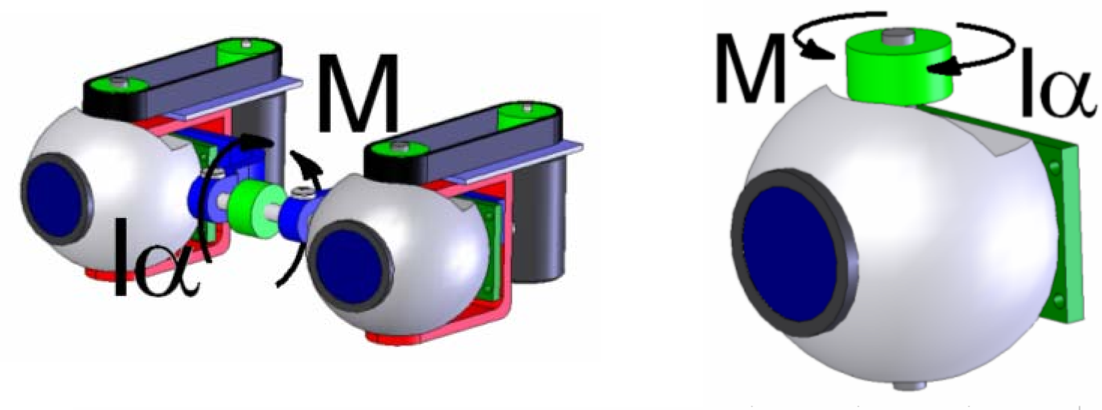


Figure 11 - CAD Model of the Eyes Mechanism

The calculation of the actuators design characteristics was based on the desired specifications and the Moments of Inertia, as well as the different components weight, given by the CAD software (Table.4).



		d (m)	m (Kg)	Fg (N)	I (Kg.m^2)	θ (°)	Ang. Acceleration (°/s^2)	mNm
Eye	pan	0,007	0,037	0,3626	0,0000065	90	1440,0	2,70
	tilt	0,012	0,13	1,274	0,000086	90	1280,0	17,21

Table 4 - Torque Calculation

2.3 External Cover

Because iCUB is meant to be act in a social environment, there is the concerns of understanding which facial features and dimensions will most dramatically contribute to the ability to convey expressions and communicate (non-verbally) with humans.
This research is important for the fields of human-computer interaction and the impact of design on this field has to be well understood. General dimensions of the different parts of the robot and the total number of facial features are some examples that heavily influence the perception of humanness in robots. The appearance of this head is being analysed by IST and AlmaDesign and inputs are expected from the University of Hertfordshire.

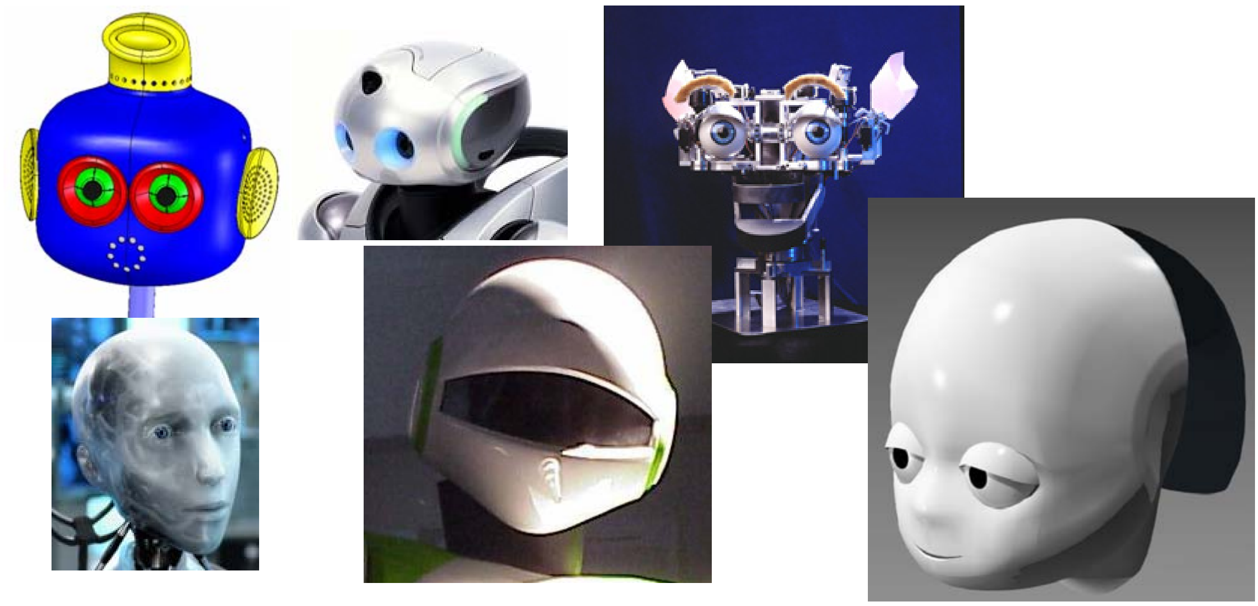


Figure 12 - Examples of Robot Heads and (very) preliminary design (rightmost image).

The external <u>cover</u> must also ensure the protection of the head mechanisms, absorbing the external efforts, suffered by the robot during operation.

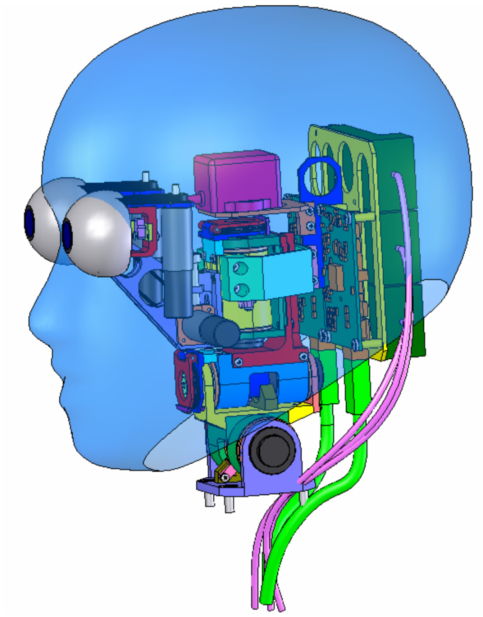


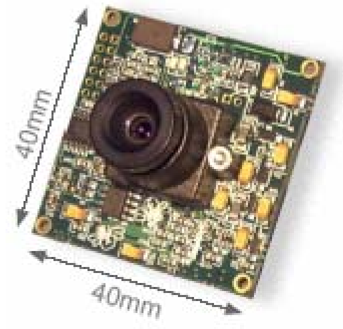
Figure 13 - Cover integration with mechanisms and electronics

3 Electrical Components

Regarding the choice of the electrical components of the iCUB head, the main are related to the extreme limitations of weight and size. In this section, some solutions of electrical components and sensors are introduced.

3.1 Camera System

Cameras Specifications	
Dragonfly	**Firefly 2**
Imaging Device	
1/3'' Sony CCD 640x480 Option: ICX084, B&W or Color 1024x768 Option: ICX204, B&W or Color HAD image sensor with square pixels Progressive scan	1/4'' Sony CCD (ICX098AK) Color VGA 640x480 format HAD image sensor with square pixels Progressive scan
Supported frame rates:	
640x480 Option: 30, 15, 7.5, 3.75 FPS 1024x768 Option: 15, 7.5, 3.75, 1.875 FPS	3.75, 7.5, 15 & 30 FPS
Signal to noise ratio:	
> 60dB	>40dB
Supported formats	
B&W models: 8-bit or 16-bit Mono Color models: 8-bit or 16-bit Bayer tiled image (color space conversion done on	YUV 4:1:1, YUV 4:2:2, YUV 4:4:4, and RGB 24-bit

the host computer)	
Synchronization: < 120µs	
Dimensions	
64 X 51mm	40 x 40mm
	

3.2 Microphones

Model	**Shure – Model MX183**	**RS – Model 242-8911**
Type	Condenser (electret bias)	Condenser (electret bias)
Frequency Response	50 to 17,000 Hz	de 50Hz a 16kHz
Polar Pattern	Omnidirectional	Omnidirectional
Open Circuit Sensitivity (at 1 kHz, ref. 1V/Pascal*)	–27.5 dB (42.2 mV)	-65dB □3dB
Max SPL (1kHz at 1%THD, 1 kΩ load	116.7 dB	not specified
Equivalent Output Noise (A-weighted)	20.5 dB	not specified
Signal to Noise Ratio (referenced at 94 dB SPL)	73.5 dB	not specified
Power Requirements:	11 to 52 Vdc phantom, 2.0 mA	1,5 Vdc
Output Impedance	180Ω	1.000Ω
Dimension	12 x 22 mm	8×18mm
		

Obs: The microphone Shure MX183 will probably be the fnial choice due to its superior specifications and in spite of its higher cost.

3.3 Inertial sensor

	Xsens MTi				InterSense InertiaCube 2			
	Output				**Output**			
	3D orientation (Quaternions/Matrix/Euler angles) 3D acceleration 3D rate-of-turn 3D earth-magnetic field (normalized) Temperature				3D orientation ------ 3D rate-of-turn ------ ------			
	Orientation performance				**Orientation performance**			
Dynamic Range:	all angles in 3D				all angles in 3D			
Angular Resolution[1]:	0.05 deg				0.01deg(Enhancement filter off=0) 0.05(Enhancement filter full=2)			
Static Accuracy (Roll/Pitch):	<0.5 deg				1 deg RMS			
Static Accuracy[2] (Heading):	<1 deg				1 deg RMS			
Dynamic Accuracy[3]:	2 deg RMS				3 deg RMS			
	Sensor performance				**Sensor performance**			
	rate of turn	**acceleration**	**magnetic field**	**temperature**	**rate of turn**	**acceleration**	**magnetic field**	**temperature**
Dimensions	3 axes	3 axes	3 axes	-	3 axes			
Full Scale (standard)	± 300 deg/s	± 17 m/s^2	± 750 mGauss	-55…+125 °C	1200 deg/s			
Linearity	0.1% of FS	0.2% of FS	0.2% of FS	<1% of FS				
Bias stability4 (1σ)	5 deg/s	0.02 m/s^2	0.5 mGauss	0.5 °C accuracy				
Scale Factor stability4 (1σ)	-	0.0005	0.005	-				
Noise density	0.1deg/s/v Hz	0.001 m/s^2/v Hz	0.5 mGauss (1σ)	-				
Alignment error	0.1 deg	0.1 deg	0.1 deg	-				
Bandwidth (standard)	40 Hz	30 Hz	10 Hz	-				
	Options				**Options**			
Full Scale	± 150 deg/s	± 100 m/s^2	-	-				
	± 900 deg/s		-	-				
	± 1200 deg/s		-	-				
	Interfacing				**Interfacing**			
Max update rate:	512 Hz (calibrated sensor data) 100 Hz (orientation data)				180 Hz			
Digital interface:	RS-232, RS-422 and USB (external converter)				RS-232 and USB (external converter)			
Analog interface (optional):	0 - 3.3V (Roll, Pitch, Heading)				-----			
Operating voltage:	4.5 - 15Vdc				6 Vdc			
Power consumption:	360 mW (orientation output)				600mW			
	Housing				**Housing**			
Dimensions:	58x58x22 mm (WxLxH)				29x25x34 mm (WxLxH)			
Weight:	50 g				25g			
Ambient temperature operating range:	0 - 55 deg Celsius				0 – 50 deg Celsius			
Obs.	1- 1σ standard deviation of zero-mean angular random walk 2- in homogenous magnetic environment 3- may depend on type of motion 4- deviation over operating temperature range (1σ) specifications subject to change without notice							
								

O sensor Xsens MTI tem grandes vantagens em relação ao Inertia Cube 2. Entre elas podemos destacar:
1 - Maior número de dados de saída;
2 - Software aberto
3 - Saída analógica
Os fatores negativos do Xsens, são o tamanho e peso, mas esses fatores podem ser contornados em nosso projecto.

4 Future Work

- External Cover (Head and Neck) design and integration,
- Introduction of Facial Expressions,
- Impact Analysis using a Finite Element Methods,
- Production of a new and more robust Serial Mechanism ,

- Analysis of new possible solution for the neck, like the Parallel Solution with an extra motor for the pan movement or the Telerobot Neck Solution,
- Development of tracking algorithms, based on low-level behaviours, in order to test the different prototyped solutions and redesign the final solution

5. References

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